Annual Progress Report (Year 2: 2005-2006)
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Project Title
Acoustic Measurements of Particulate Organic Carbon Concentrations in the Coastal Ocean

Project Duration
05/01/04 to 04/30/07

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Preface

During the summer of 2005 one of the PIs (Dr. Miguel Goni) moved to Oregon State University. Although this re-organization created a small delay in the progress of the project, the overall objectives and deliverables remain unchanged. In addition, funds for the 2nd year of research were not made available to the researchers until the fall of 2005, limiting the productivity of personnel whose salaries depended in this NOAA project. Nevertheless, considerable progress has been made in the remainder of the year, as explained below.

Project Goals

The project goal of this proposal is to investigate the use of optical and acoustic backscatter (OB and AB, respectively) as quantitative measurements for particulate organic carbon (POC) concentrations in coastal ocean water columns. The long-term objective of this proposal is to establish the methodology and protocol for the inclusion of POC concentrations and fluxes in routine monitoring measurements currently undertaken by NOAA and other federal and academic institutions as part of the coastal monitoring efforts. Our short-term objectives aim at developing the methodology and proof of concept in a limited number of sites representing different environmental settings.

In particular, the specific objectives of our proposed work include:

1) Determination of the chemical basis for the POC – suspended particulate matter (SPM) relationships in different coastal waters.
2) Establishing the relationships between SPM concentrations, OB and AB in different environments.
3) Development of OB–POC and AB - POC algorithms to estimate POC concentrations.

Methods

Field Sampling

We are profiling the water column at different ocean margin environments including estuaries, inner and outer shelf, in the South Atlantic Bight. At each profile site CTD, optical backscatter sensors (OBS), fluorometer and acoustic Doppler profilers (ADCP, 1200KHz and 600KHz) instruments are used to gain basic information of the water column compositions. Water samples from specific depths are being collected at the same time and used to isolate samples of suspended particles from different depths. These samples are being analyzed at the geochemical level in order to correlate POC compositions and concentrations to the in situ parameters measured by the profiling instruments.

POC Analyses and Characterization

The composition and sources of the POC are being characterized to provide chemical basis for the observed differing relationships between POC and SPM concentrations. As part of this effort, we are measuring POC and particular nitrogen (PN) concentrations, as well as the stable isotopic signatures ($\delta^{13}C$, is to be sampled $\delta^{15}N$) and organic biomarker concentrations (lignin phenols, fatty acids) of particulate organic matter. All of these analyses are being done in the laboratory using samples collected from specific depths in the water column where salinity, temperature, SPM, light transmission, optical and acoustic backscatter are being measured.

OBS and Acoustic Techniques

Optical methods have severe limitations when it comes to measuring sediment in the water column. In general, OBS sensors respond better to fine sediments and tend to underestimate the coarser particle present in the water column. One the other hand acoustic backscatter depends on the wavelength. Maximum response is achieved when $k*d \sim 1$ (where k is the acoustic wavenumber and d the radius of the particles) and decays rapidly for $k*d<1$ (i.e., finer particles assuming constant acoustic frequency) while remains at high levels for $k*d>1$. Given the fact that POC is associated with the fine sedimentary particles, we are combining data from the OBS and AB and try to differentiate between POC-rich particles and coarse OC-barren particles. Additionally, OBS and AB signals are being contrasted to filtered data in order to better quantify biological materials that can be acoustically transparent.

Results and Accomplishments

Research Cruises

During the first two years of our project, we completed two research cruises – October 2004 and March 2005 – aboard the NOAA R/V Nancy Foster along the South Carolina's coast (Fig. 1). During these cruises we intensively profiled the water column in two estuarine environments (Charleston Harbor and Winyah Bay, SC) and the inner and outer shelf regions of this part of the South Atlantic Bight using the CTD, OBS and ADCP instrumentation. Additionally, we used a fluorometer and Laser in-situ scatter transmissometer (LISST) to profile the water column and determine *in situ* chlorophyll concentrations and particle size distributions.

In October 2004, we encountered conditions of relatively low river discharge. In contrast, the March 2005 cruise took place during a period of relatively high river discharge. Overall, we completed over 200 casts and over 500 individual water samples were collected during the two field campaigns. ADCP data were continuously recorded during operations. Ship-related problems during the March 2005 cruise limited the number of days available for science. For that reason, most of our efforts were focused on sampling along the Winyah Bay transect. The analyses of the in-situ measurements and the geochemical analyses of the isolated particulate samples are currently being carried out.

Scientific Findings & Advances

Our initial focus in this research has been in understanding the particle dynamics in Winyah Bay, an important river dominated estuary. Over the past few years, we have been investigating the distribution, composition and fluxes of SPM and POC along Winyah bay over several full tidal cycles (Figure 2) under contrasting conditions of river discharge (Figure 3). The results of these efforts are illustrated in Figures 4, showing variations in the salinity, and SPM concentrations over the whole water column at four of the stations profiled ca. every 3 hours. We used these data, along with individual samples collected at three different water depths, to derive a relationship between POC and SSC concentrations and the OBS and AB (from the ADCP) signals.

We have measured significant differences in the relationship between POC, SSC, OBS and AB signals that are consistent with differences in the composition and nature of the particulate load during different discharge regimes (Figures 5 and 6). For example, Figure 4 shows the distinct relationships between OBS and SSC under low and high discharges. Figure 5 shows the distinct relationships between POC and SPM for different cruises and river discharge regimes. Figure 7 shows an example the relationship between SPM and AB. We have compiled several robust empirical algorithms that relate the concentrations of POC and SPM to OBS and AB signals and allow us to produce detailed reconstructions of their water column profiles (Figure 8). We have used these relationships coupled with current profile measurements to calculate the net fluxes of POC and SPM across different stations within Winyah Bay for different discharge regimes. Figure 9 shows an example of these calculations in which we have divided the net fluxes into two constituents, mean fluxes and tidal fluxes.

Outreach Efforts

During the March 2005 cruise, in collaboration with the NOAA Marine and Aviation Operations, Education and Teacher at Sea Program, we hosted a group of Albert Einstein Distinguished Educator Fellow Recipients, which consisted of K-12 Science and Mathematics Teachers. The group of teachers came on board the Nancy Foster and received a lecture on estuarine processes and the relationship to basic physics, math and chemistry as it applies to the classroom. In addition, they participated in the data collection and analysis program and gained invaluable hands-on experience in oceanographic research. It should be emphasized that fellows participated in the deployment of instrumentation, collection of data and water samples, and were fully integrated into the research activities during the cruise according to the science plan and was not part of a demonstration routine. Their contribution was invaluable and appreciated in this research. According to the feedback we received this experience proved to be highly productive and we hope it will serve as a model for future similar efforts.

Future Research

In the next year, we plan to continue analyzing the data and samples collected to date. We will expand the investigations to non-estuarine settings in the inner and outer shelf of the South Atlantic Bight and include samples collected during high discharge periods (March 2005). Laboratory experiments are being started to calibrate the AB response of different ADCP instrumentation to different sediment types, i.e. different grain sizes, composition. For this purpose a recirculating tank has been currently developed at the University of South Carolina (see Figure 10). Additional sampling and data collection are planned in shelf environments from the South Atlantic Bight. We are also planning to submit and write several manuscripts describing the results to date.

Publications Resulting from this Research:

Goñi M. A., Cathey M. W., Kim Y. H., and Voulgaris G., 2005, Fluxes and sources of suspended organic matter in an estuarine turbidity maximum region during low discharge conditions: *Estuarine, Coastal and Shelf Sciences, 63*: 683-700.

Kim, Y.H. & Voulgaris, G. Effect of Channel Biffurcation on Residual Estuarine Circulation: Winyah Bay, South Carolina. *Estuarine, Coastal and Shelf Science, 65:* 671-686.

Kim, Y.H., B. Gutierrez, T. Nelson, A. Dumars, M. Maza, H. Perales and G. Voulgaris, 2004. Using the acoustic Doppler current profiler (ADCP) to estimate suspended sediment concentration. Unpublished Technical Report CPSD#04-01, Coastal Processes and Sediment Dynamics Laboratory, Department of Geological Sciences, University of South Carolina, Columbia, SC., December 2004. 20pp.

Published Abstracts from Presentations Resulting from this Research:

Kim, Y., Voulgaris, G., Goni, M.A., 2006. Particulate organic carbon (POC) fluxes across an estuary using acoustic and optical sensors. *Eos Trans. AGU, 87*(36), Ocean Sci. Meet. Suppl., Abstract OS25G-172006

Kim, Y.H., Voulgaris, G., Goni, M.A., 2005. Estimation of particulate organic carbon (POC) fluxes using acoustic and optical sensors in estuaries. ASLO Summer Meeting. June 19-24, 2005. Santiago de Compostela Spain, p. 80.

Goni, M.A., Voulgaris, G., Cathey, M. W., Kim, Y. H., 2005. Sources and fluxes of suspended organic matter in an estuary turbidity maximum region. ASLO Summer Meeting. June 19-24, 2005. Santiago de Compostela Spain, p. 58.

Figures

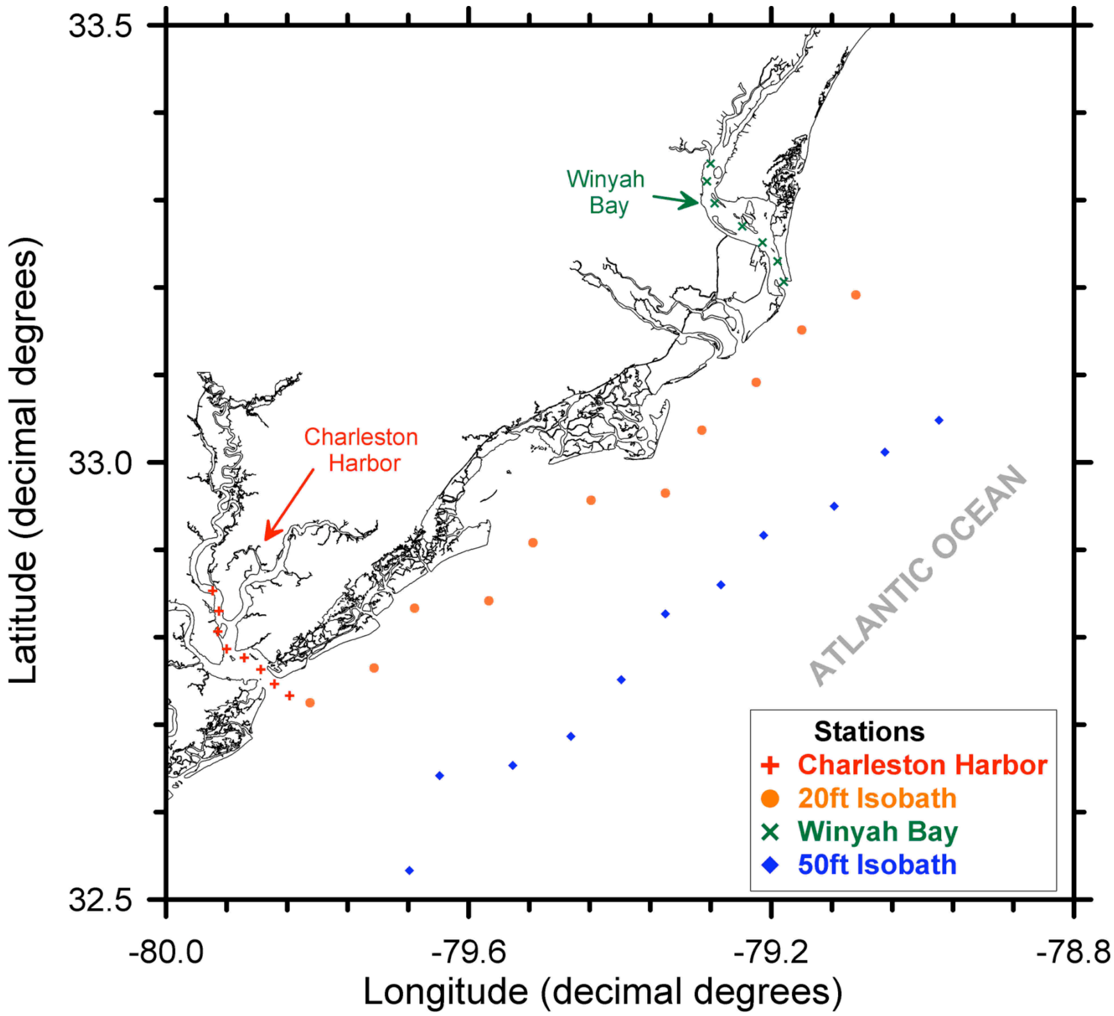

Figure 1. Map of the stations occupied during 10/04 cruise aboard NOAA's R/V Nancy Foster.

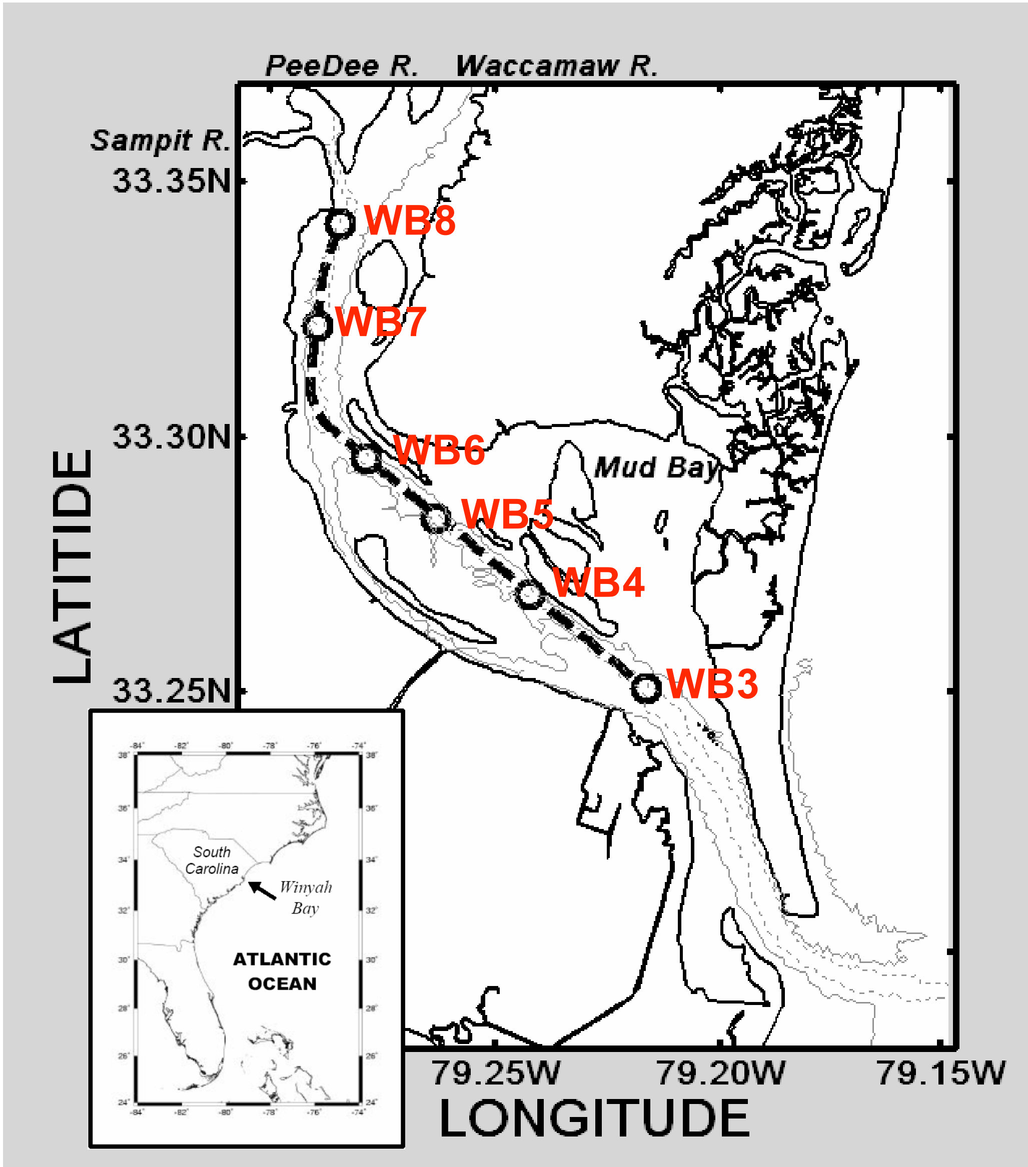

Figure 2. Map of Winyah Bay showing transect (dashed line) and cast locations occupied during the March 2005 cruise.

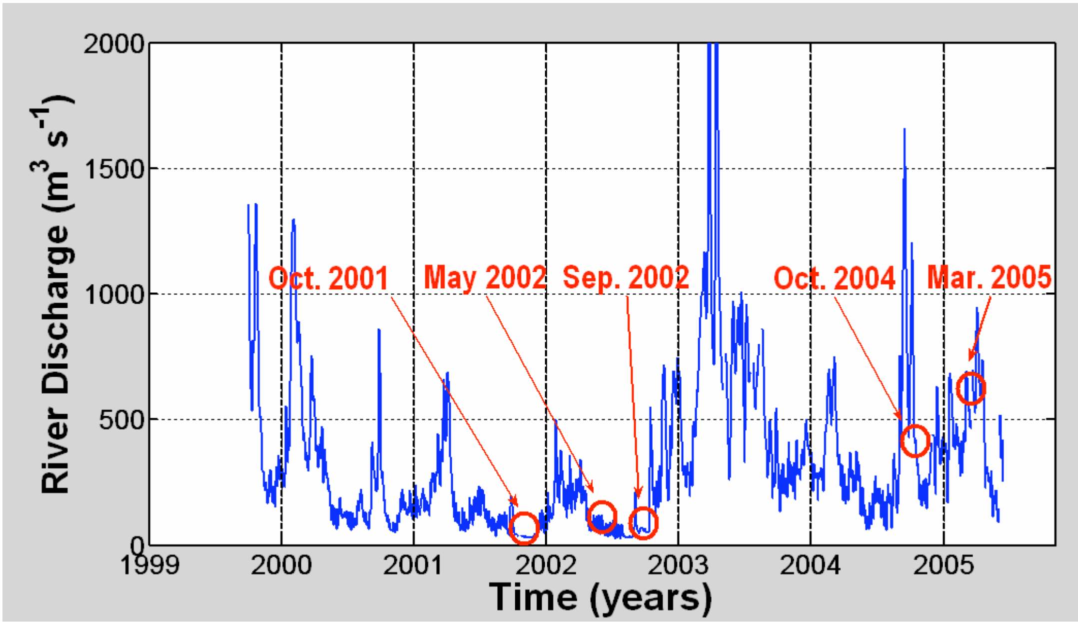

Figure 3. Total freshwater discharge from the five rivers (PeeDee, Little PeeDee, Waccamaw, Black, and Sampit rivers) that flow into Winyah Bay estuary (*Data from: http://waterdata.usgs.gov/nwis/sw*. Indicated are the timing of the research cruises conducted in Winyah Bay from which we are processing data and samples.

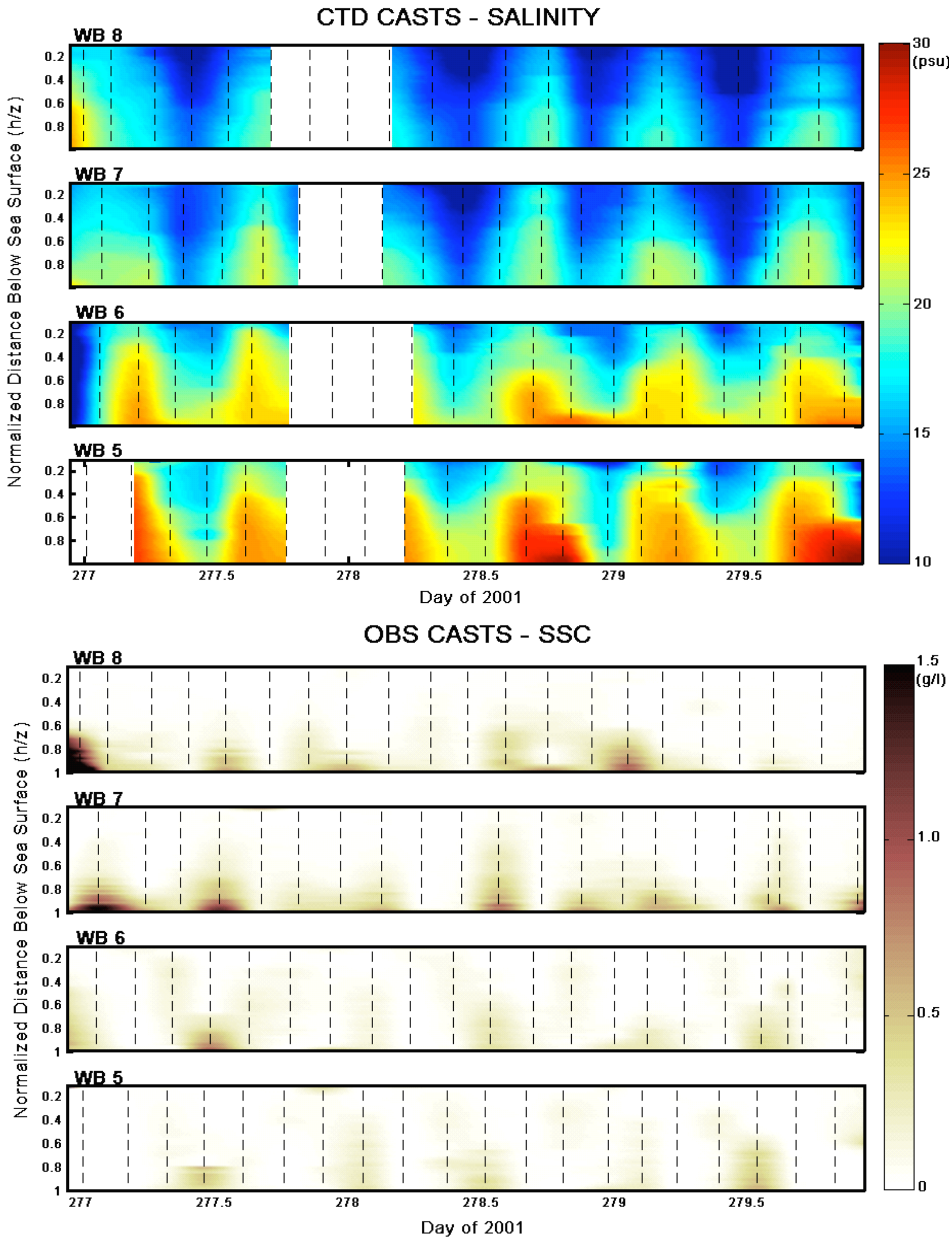

Figure 4. Time-series of vertical variability of salinity and suspended sediment concentration (SSC) at four Winyah Bay stations (WB5, WB6, WB7 and WB8, see Figure 2 for locations).

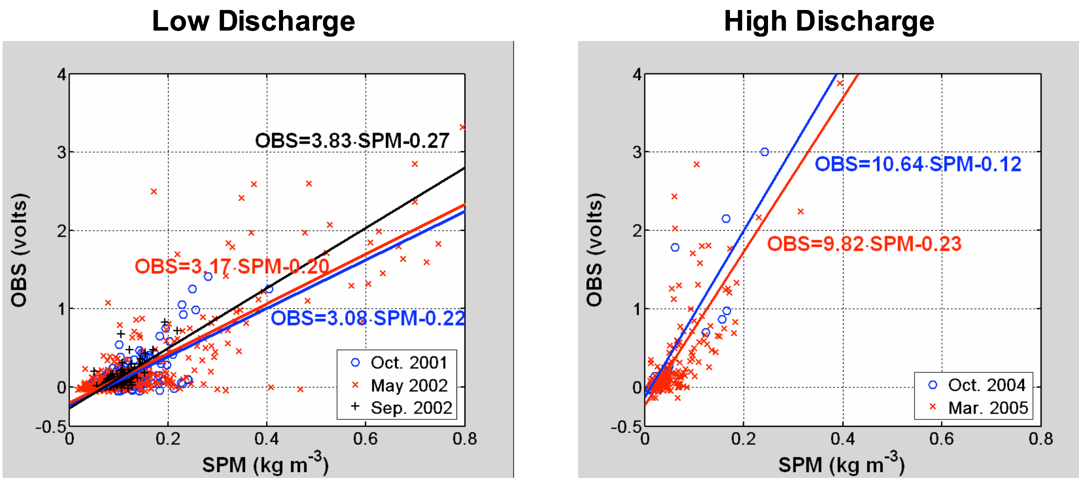

Figure 5. OBS signal (in Volts) versus SPM concentration (obtained from water samples) for low (left panel) and high (right panel) river discharge conditions. Note the higher response of the OBS during the high discharge conditions indicating greater response probably due to a dominance of fine material in the water column.

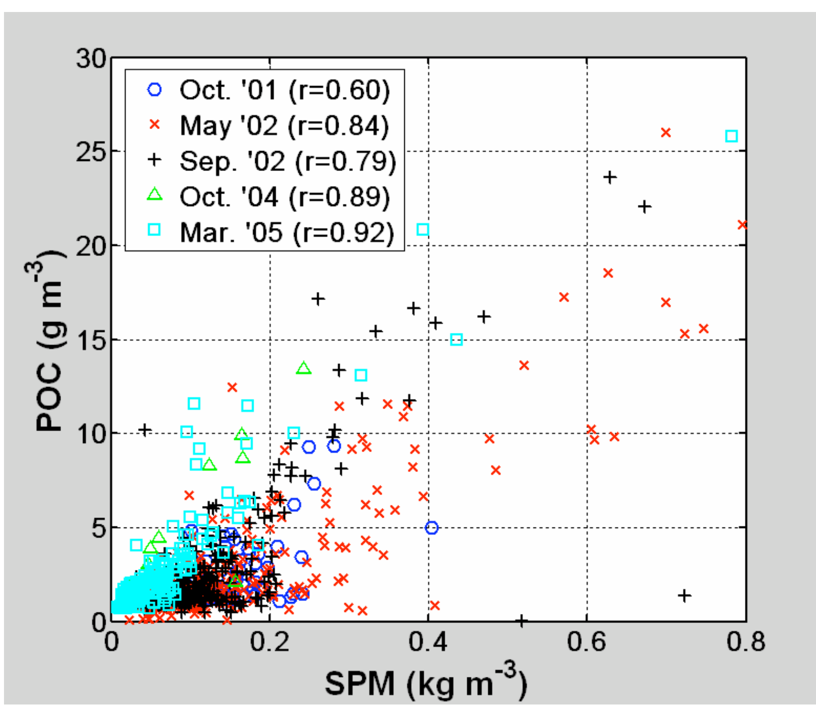

Figure 6. SPM vs. POC concentration. POC concentrations have a positive relationship with SPM concentrations with correlation coefficient of 0.60-0.92. This suggests that optic proxies can also be correlated to POC concentrations in this estuarine system.

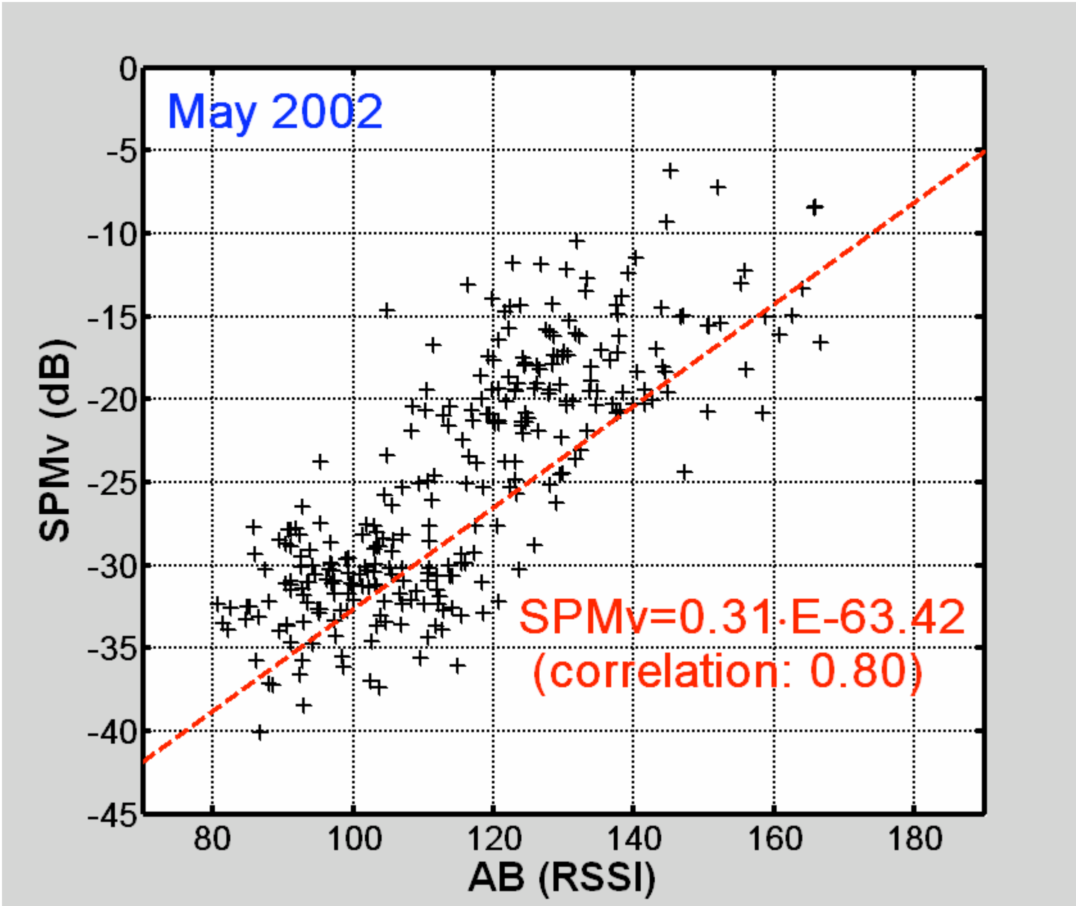

Figure 7. Acoustic backscatter intensity (AB) from the ADCP (after it has been corrected for attenuation by sediment and water) versus total suspended sediment concentration (SPMv).

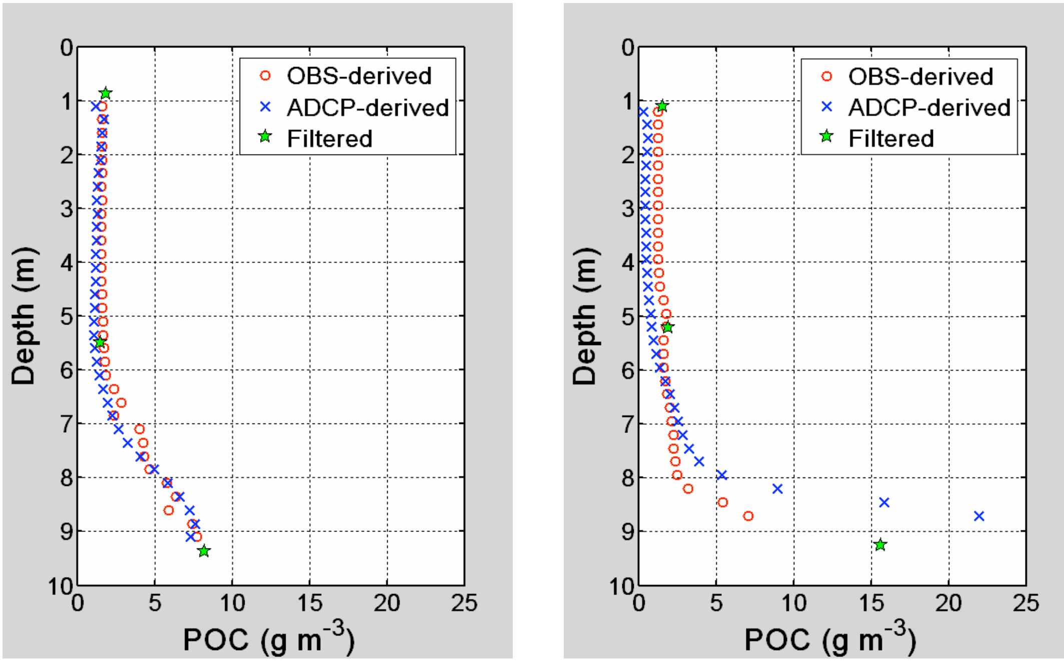

Figure 8. The relationships shown in Figures 3,4 and 5 are used with the OBS and acoustic data to provide estimates of vertical distribution of POC with high spatial resolution from the OBS (circles) and the ADCP (x's). POC concentrations from the discrete samples are also shown for comparison. Two profiles for low (left panel) and high (right panel) near-bed concentrations are shown.

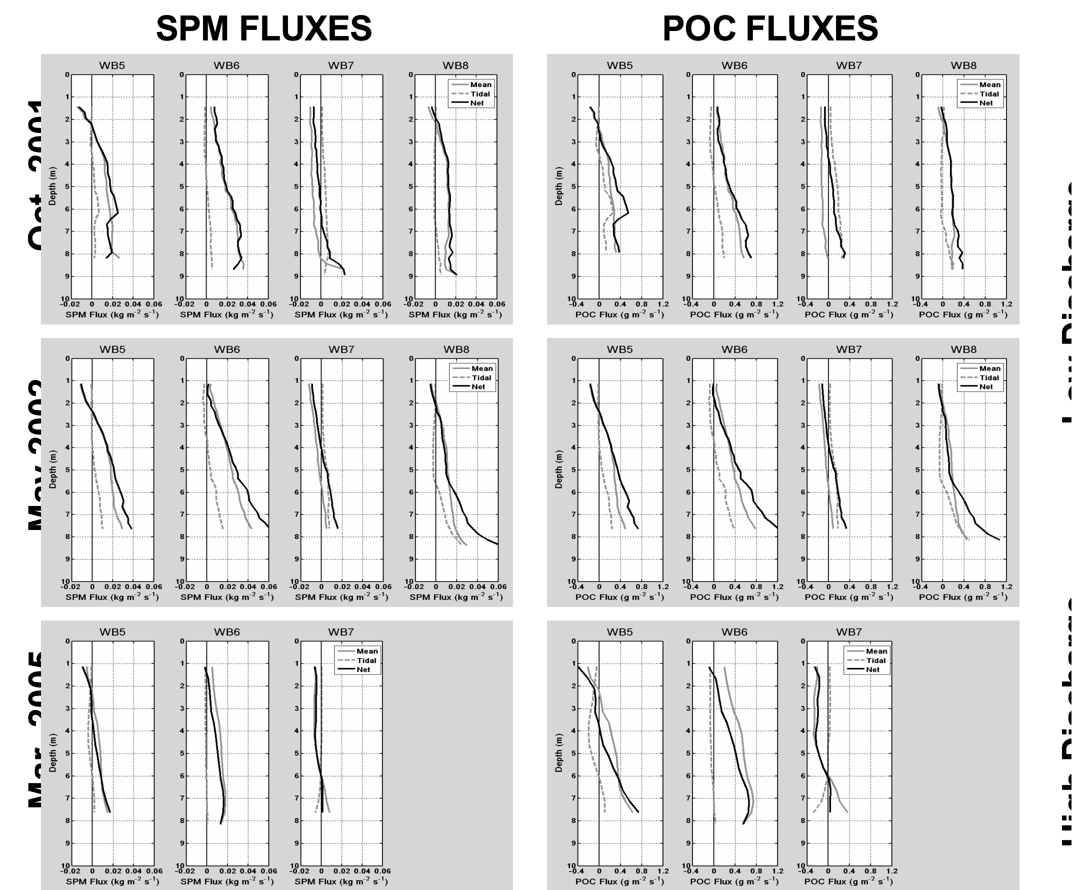

Figure 9. The high vertical and temporal resolution in estimating SPM and POC concentrations using the optical method (OBS) allows the coupling with flow measurements for the estimation of local fluxes. SPM and POC fluxes due to the residual (solid gray line) and tidal flows (dashed gray line) are shown as well as the net flux (black line), see Figure 1 for station location. Net SPM fluxes during March 2005 (high discharge period) were generally smaller than those during the low discharge period (October 2001 and May 2002). During October 2001 mean fluxes of SPM and POC accounted for 80-90% of the net flux on stations WB5, 6, and 8. The influence of tidal fluxes on these stations increased up to 30% (near the bed) during May 2005. During low discharge periods, data from station WB7 show the net flux to be directed up-estuary near the bed and to be balanced by a down-estuary net flux at the surface layer.

Figure10. Sediment recirculation chamber developed at the University of South Carolina for the investigation of the acoustic signal of particles in suspension.

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